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Grinding and Finishing

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Grinding Machines . . .

Surface Grinding

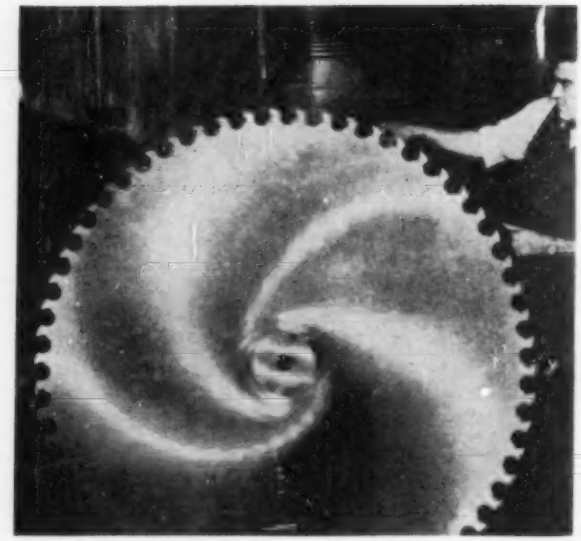
by **Albert I. Palm**, grinding engineer, The Norton Co.

WHEN ONE CONSIDERS that less than 70 years ago flat surfaces were generally evened up by the chisel or file, it can be readily seen that surface grinding has come a long way. Precision grinders of today, with their smooth hydraulic table traverse and high speed, are a far cry from earlier models of as late as 25 years ago.

Although the machines are quite easily operated, it still depends on the operator's judgment and understanding of grinding wheel behavior and his ability to quickly spot any kind of trouble and correct it that determines the worth of any grinding unit.

Machines used vary greatly; from small toolroom machines, mounting 7" diameter x ½" thick wheels, to massive face grinding machines, carrying 48", and even 60" diameter chucks securely holding abrasive segments.

More and more, the metal working industry is adopting the ground plane surface for reasons of economy and pro-



The type of work that can be handled on a vertical spindle, rotary table surface grinder is typified in this 60" circular saw. The sides are concaved for clearance.

ductivity, as well as from considerations of quality of surface finish, accuracy and appearance. Many parts formerly milled, planed, or hand scraped are now precision surface ground. Each year the trend in this direction becomes more pronounced. The wide variety of types of surface grinders and of sizes within each type now available testify to the importance industry attaches to this machine as a production tool.

Types of surface grinding machines

Surface grinding machines are divided into two types with respect to the movement of the work table:

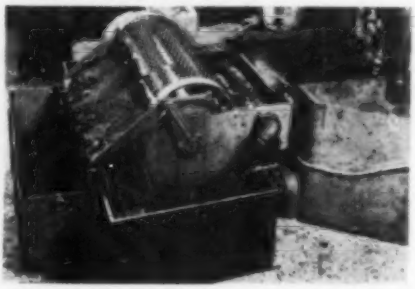
1. Planer type in which the work table reciprocates; 2. Rotary type in which the work table revolves.

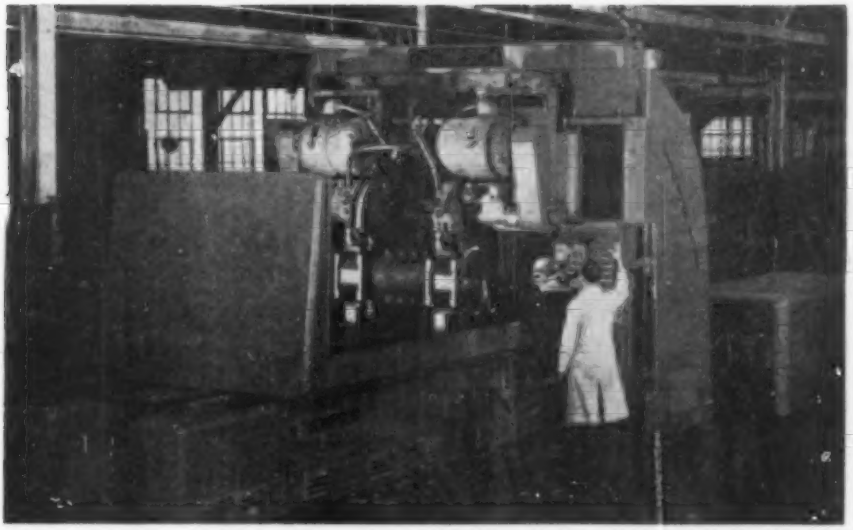
The planer and rotary types are further divided according to the type of wheel, as follows:

1. Planer type surface grinders, horizontal spindle: (a.) Using the periphery of straight wheels, such as Norton, Thompson, Mattison, Abrasive, Hill-Acme, Brown & Sharpe; (b.) Using the rim of cylinder wheels or segments such as Hanchett, Bridgeport, Rogers. **Vertical spindle:** (a.) Using the rim of cylinder wheels or segments such as Pratt & Whitney, Hanchett, Hill-Acme,

2. Rotary type surface grinders, horizontal spindle: Using the periphery of straight wheels, such as Heald and Arter; **vertical spindle,** using the rim of cylinder wheels or segments such as Blanchard and Hanchett.

When the rate of metal removal runs high, a great factor is the problem of chip disposal; this is a magnetic separator, one means of solving it.





Hydrail machine 75 x 36 x 120 with dual wheel heads setup for grinding horn guide wear strips in anti-friction locomotive drive box.

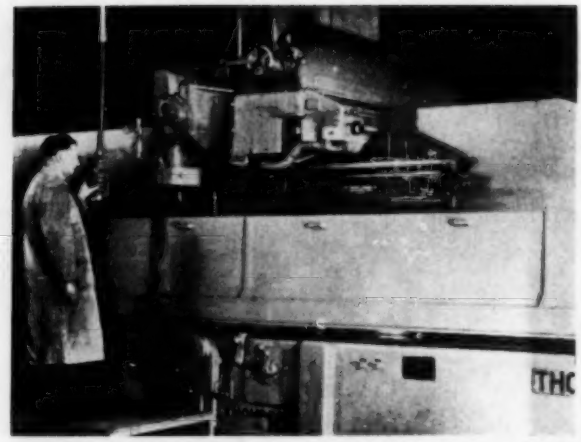
General suggestions for surface grinding

Care of Machine. In order to produce the best results in surface grinding, it is essential that the precision built machine be properly cared for. Close attention should be paid to such important details as lubrication, particularly of the wheel spindle and table ways, condition of the magnetic chuck, the level and grade of oil in the hydraulic system, and even the matter of keeping the machine as clean as possible.

Wheel balance. Where a straight wheel is used, it is essential that the grinding wheel run perfectly true and without vibration to produce a chatter-free finish. On the larger machines, it is good practice to first rough true the wheel when newly mounted on its own sleeve, balance it carefully by means of the balancing weights provided in the wheel sleeve and then finish true it.

Design of parts to be ground. It is general practice to leave a fairly large amount of stock to be removed when planing or milling operations are to be

This is one type of rotary surface grinder.



Heavy duty surface grinder with dual wheel heads for grinding both the flat and V-ways of lathe beds.

performed to allow for removal of scale and hard spots. The present trend is to eliminate preliminary machining wherever possible so that the grinding operation removes the scale and produces the desired dimensions and finish in one step. In this case, much less stock is left on casting.

Coolants. Wet grinding is generally preferred to dry grinding since longer wheel life, better finishes, and faster rates of production can be obtained. In wet grinding, a full stream of coolant is desirable, especially inside the wheel in the case of cylinder, cup or segment type wheels, since overheating can cause distortion of the work piece and magnetic chuck. It is always good practice also to use the outside nozzle to assist in keeping the work cool.

If the stream from inside the wheel becomes small, or stops completely when the outside nozzle is wide open, it of course indicates either too little coolant in the tank, or that the coolant piping system is clogged. The level in the tank should always be kept high and the settling tank cleaned out at frequent intervals to insure an ample supply of clean coolant at proper temperatures. The coolant filter is of the utmost importance and should be cleaned frequently so that sufficient coolant is provided. Grinding fluids prevent overheating of the wheel and the work and its lubricating and detergent properties help to keep the wheel face clean and free cutting.

For the general run of steels and cast iron, the most common grinding fluids are of the water-emulsion type and are generally used in a ratio of one part oil to 50 parts water. Metals which tend to load the wheel, such as aluminum and certain stainless steels, require high detergent oils to retard wheel loading.

Cylinders versus segments. To produce the best finishes on vertical spindle surface grinders, a cylinder type wheel is generally preferred to a segment type wheel. When using fine grit, soft grade cylinder wheels, finishes of 5 microinch r.m.s. and better can be obtained.

Either cylinder or segment wheels may be used, however, to produce ordinary commercial finishes, and the advantage of the segment type wheel, of course, is its cooler and faster cutting ability (as a result of its interrupted

Face grinder with traveling table equipped with a 42" segmental grinding wheel.

grinding surface) with consequent lower overall grinding costs.

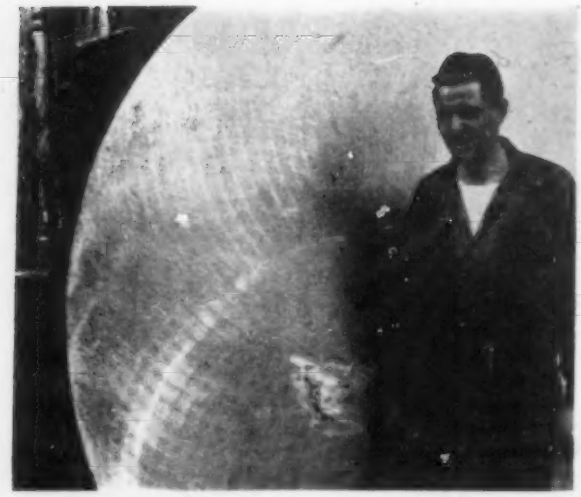
Surface grinding troubles and their remedies

Work not flat. A part having a comparatively thin section may spring slightly during grinding, causing more or less variation in flatness. The magnetic pull on thin work that is slightly warped may be sufficient to draw down the warp to be removed. Such work, if not too thin, often can be ground flat simply by placing it on the chuck without magnetizing it, but blocking it at both ends to prevent its sliding on the chuck.

Do not hurry the grinding. Take very light cuts on the finishing passes so as not to overheat and distort the work. Be sure the grinding wheel face is clean and sharp. Be sure the wheel is of the proper abrasive, grit size and grade for the material being ground and the finish required; then dress the wheel accurately to keep it sharp and cool cutting.

Be sure the material is as free as possible from any internal stresses before finish grinding. Work that has been heat treated should first be rough ground in order to relieve the internal stresses set up in the heat treatment. The rough grind may leave the work slightly distorted. The procedure then is to pack the work with paper strips, or shim stock, and grind one surface flat; then, finish grind the other surface parallel to, or square with, that surface.

Needless to say, in order to produce perfectly flat work, the machine should be thoroughly cleaned before starting to finish grind. The magnetic chuck,



When the spindle on a vertical spindle surface grinder, is exactly square with the chuck face, this characteristic cross pattern is the result.

particularly should be wiped clean and stoned off.

Work out of parallel. This fault is usually traceable to some inaccuracy that has developed in the face of the magnetic chuck. Inspect the chuck for any surface roughness. It is a good practice to rub the chuck lightly all over between jobs with either a fine grit India or Crystolon oilstone to remove any burrs that may have been thrown up by rough castings.

Just as soon as the chuck becomes scratched or worn enough to effect the accuracy of the work, it should be reground. If a circular chuck, check it for flatness by laying a straightedge across its center. If a long rectangular chuck, use a dial indicator clamped to some convenient part of the work head, like the wheel guard. The maximum variation should not exceed 0.0005" if the chuck has been properly ground.

Between loadings, the magnetic chuck should be wiped off carefully, using a piece of flat leather belting.

If the work to be ground is a rough casting that has not been previously machined, file the base or grind it on a disc grinder to a clean and reasonably flat and smooth surface for solid seating on the magnetic chuck.

Do not permit the wheel to run off the work entirely at either end of the grinding stroke on horizontal spindle, rotary table machines, nor at the end of the cross-feed on reciprocating table machines, as this will cause the outside edges of the work to become slightly rounded.

Work out of square. The procedure usually followed in grinding the work square is to first grind two sides parallel, then mount the work in a vise held by the magnetic chuck and grind one side square. The work can then be turned over on the magnetic chuck itself and the opposite side will be ground square; or the vise may be used again. If the work is cylindrical or irregularly shaped, the bottom surface should be packed, using a toolmaker's square to be sure that the side of the work is perpendicular to the face of the chuck.

Scratching of work. Irregular "fish-tail" scratches of varying lengths and widths are generally caused by dirty

coolant or loose particles of dirt from underneath the wheel guard. It is good practice to flush the underside of the guard when changing wheels.

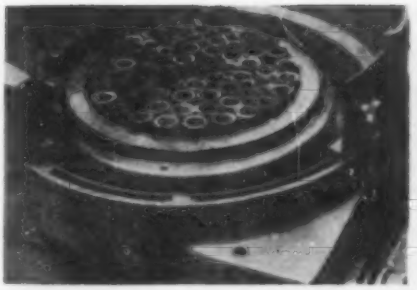
Improper wheel dressing with a diamond will cause a pattern of scratches, or "diamond marks," on the work surface. Make sure the diamond is not cracked or loose in its setting and is properly slanted toward the wheel. Give the diamond a quarter turn every few dressings. Traverse the diamond across the wheel face slowly and evenly. If feed lines from peripheral type wheels persist, round off the edges slightly.

Do not slide the work off the magnetic chuck as this will scratch both the work and the chuck. As a rule, the work can be easily lifted after demagnetizing the chuck.

To protect the ground surfaces of flat steel sheets from being scratched, separate the pieces with strips of oiled paper as each piece is ground.

Burning or checking of the work. Discoloration of the ground surface of steel work pieces is evidence that the surface has been burned and, if hardened steel, probably checked. The grinding wheel may be too hard, in which case, a softer, freer cutting wheel should be used, or the operating conditions changed so as to give the wheel softer grinding action. Increasing the table speed, giving the wheel a coarser dressing, or reducing the area of grinding contact by truing the face or rim to a narrower width will help to achieve this result.

Work sliding on the magnetic chuck. Stops of some sort must be used to prevent work from sliding. The magnetic chuck holds the pieces down but does not hold them sideways, except by friction between the piece and the chuck face. Therefore, light pieces should always be blocked either sideways or endways, depending upon the type of surface grinder, to prevent the work from sliding or spinning.



By omitting two innermost rows of parts, the grinding cycle was speeded up in this operation. Avoid filling chuck area completely.

On vertical spindle, reciprocating table type machines, the work should be placed on the chuck so that it is under the center line of the wheel when grinding. This neutralizes the forces that would tend to spin the work.

Wheel loading. Metal lodged in the wheel pores indicates a loaded wheel. Use either a coarser grit wheel or a porous type (open structure) wheel to provide more chip clearance, or a softer grade wheel that will break down more readily. If the wheel is loading because it is slightly hard, try increasing the table speed. In this connection, it is well to remember that when grinding on a rotary table machine, the work speed near the center of the table is much less than that at the outside edge. Thus, for a small piece chucked near the center, a relatively high table rotation speed should be used.

If loading persists, check the diamond to be sure it is sharp and give the wheel a very open or coarse dressing by using a relatively heavy feed and rapid traverse. Check the supply of coolant flowing on to the wheel and the work, and be sure it is not dirty or too oily. High detergency (ability to keep the wheel face clean and sharp) is an important

Hand stoning the chuck of a rotary surface grinder. Between jobs, it is good practice to rub over the chuck surface with a fine or medium oilstone to remove any burrs.

property of water soluble grinding fluids.

Wheel glazing. Inexperienced operators on vertical spindle rotary table type machines are sometimes prone to use too light downfeeds because of fear of burning and displacing the work. This causes the wheel to glaze since there is insufficient pressure to break down the wheel face. Simply increasing the downfeed will correct this condition.

Glazed wheels are also caused by insufficient coolant, too hard grade wheels and too fine grit wheels. Checking the diamond to make sure it is sharp and giving the wheel as coarse a dressing as the finishing requirements will permit are also helpful.

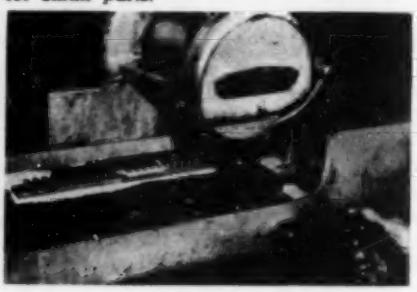
Chatter Marks. These are caused by vibration from one source or another. On surface grinders of either the rotary or reciprocating table type employing the periphery of a straight wheel, chatter marks can result from any one of several conditions, such as worn, or inadequately lubricated wheel spindle, or other vital moving parts, wrong table speed, wheel out of balance, or out of truth, wheel too hard, lack of solid foundation for the machine, or proximity to vibrating machines, such as punch presses.

On light finishing cuts, the grinding wheel may glaze, become dulled and leave chatter marks on the work. This condition is usually corrected by redressing the wheel with a sharp diamond and taking a minimum number of passes to produce the desired surface and accuracy.

On machines equipped with a balancing type wheel sleeve, balance the wheel assembly before starting to grind with a new wheel. Be sure also to rough true the wheel on the machine before balancing it in the conventional manner on a balancing stand and then finish true the wheel after remounting on the machine.

Grooved and slotted surfaces. The grinding of a flat surface containing grooves or slots, such as cast iron cored plates for hydraulic machine tools, is an unusually exacting job. A typical plate presents a honeycomb of holes and cored slots and must be ground perfectly flat in order to hold 125 pounds oil pressure in the grooves without the use of a gasket. To keep the edges of the grooves absolutely square, as required, the wheel must be sharp and free cutting throughout the grinding cycle; any dulling of the wheel causes pressure to be built up and when the wheel approaches a groove, the reduced contact area permits the wheel to cut deeper, thereby destroying the surface flatness.

This shows the permanent type magnetic chuck that has adequate holding power for small parts.

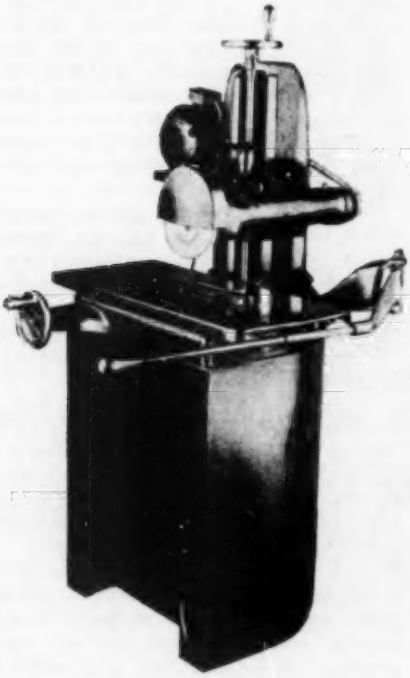


Descriptions of late model surface grinding machines

Crosman's utility t-square action

J. B. Crosman & Son, Inc., East Walpole, Mass., manufacture an improved surface grinding machine on which tools, dies and small machine parts can be accurately and quickly ground. The t-square action principle does away with the usual intermediate table or alternative moving spindle housing. The table rests directly upon the plane ground surface of the bed and is guided longitudinally and laterally by the t-square action control.

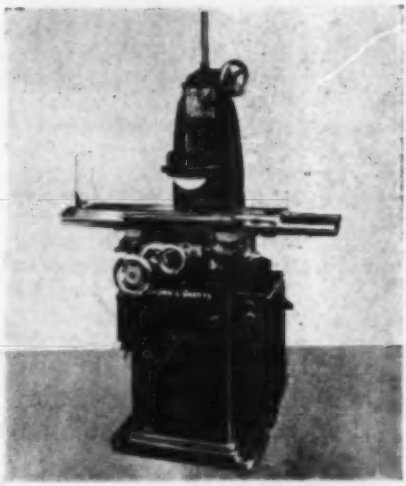
Either bench or floor mountings are offered with Crosman's t-surface grinding machines. The motor drives the spindle through a flat belt, and is mounted on a pivoted base readily adjustable to give proper belt tension. A 1/3 h.p., 110 volt, 60 cycle, single phase, standard motor is regularly furnished. A 1/2 h.p. motor of any current characteristics can be furnished when necessary for greater stock removal.



B & S 2L and 2LB

These machines are designed and built for efficient surface grinding with precision and fine finish on small and medium size work, by Brown & Sharpe Mfg. Co., Providence, R.I.

Some of the features are: (1) convenient controls for fast, accurate manipulation; (2) two rates of table feet (2L machine)—19 ft. or 31 ft. per



minute; (3) precision wheel spindle provides exceptional grinding finish with quick spark-out; (4) full automatic lubrication and strategically-placed dust guards; (5) rigid column construction; (6) electrical controls enclosed in separate compartment.

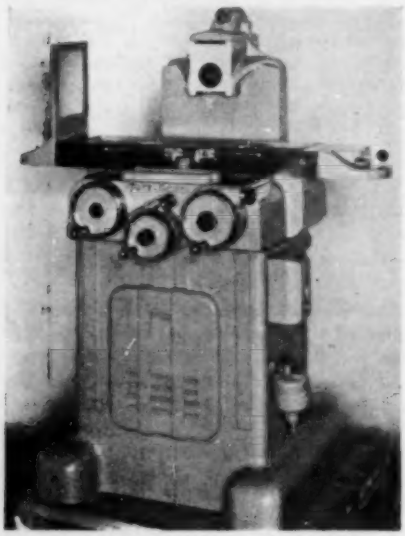
The convenient location of all controls and adjustments permits rapid

setup and provides exceptional ease and efficiency of operation for greater production and less fatigue. There is automatic lubrication.

Taft-Peirce No. 1

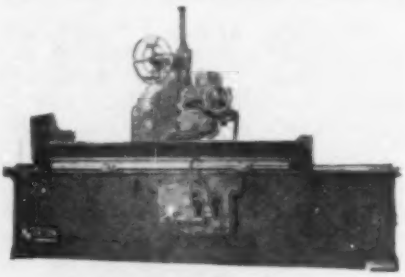
The No. 1, precision surface grinder made by The Taft-Peirce Mfg. Co., Woonsocket, R.I., is built more sturdily than many machines of this type. Ball mountings and bearings throughout permit extreme precision and uniformity of the parallel and rectilinear motions which are indispensable to precision surface grinding. This assures extremely close limits of tolerance. Among features is a tilting wheelhead which makes the machine suitable for difficult angle and shoulder work. There are hardened and ground ways and the table, saddle and column move on ball bearings.

The grinder employs a unique feature in the mounting of the wheel spindle, which swivels in a vertical plane about the center of the wheel. The spindle is carried in an accurately bored cast iron block mounted between two pairs of circular dovetail slides, permitting swiveling of the entire spindle about the wheel center through an arc from horizontal to 30° below center



Norton 10" hydraulic

This 10" hydraulic surface grinder made by The Norton Co., Worcester 6, Mass., is a heavy duty reciprocating table-type machine. Table reciprocation is accomplished hydraulically by an improved type of hydraulic drive. Automatic and hand cross feed arrangements are supplied. Wet grinding attachment complete with pump and tank included as standard equipment. Magnetic chucks and individual dust exhaust systems available as extras.



There are four sizes. Table top to wheel bottom is 12½" or 10". Table speeds, adjustable up to approximately 100 f.p.m. The wheel is a No. 1, straight 10x1½x3. The nominal lengths for the 24, 36, 48 and 60 are 98, 122, 146 and 170 respectively. The widths are all the same, 67.

DoAll tool room model

Grinders offered by DoAll Co., Des Plaines, Ill., stress performance as reflected in reliability of feed control calibrations and in finish and flatness of the work.

An outstanding feature is the fact that attachments are available to make these surface grinders virtually completely automatic. For example, the grinder can be arranged to downfeed

automatically for plunge form grinding and stop at the required place, or cross-feed and then downfeed automatically for automatic surface grinding operations.

Variable speed spindle, wheel guard innovations — unnecessary to remove guard when removing wheel—three cooling methods in one, high speed spindle attachment, variable speed cross feed control and hand wheel slip rings and operating levers are other features.

Reid Model 618V

The Reid Model 618 V precision surface grinder with variable table speed solves the problem of grinding various metals and materials of different hardnesses that are being used more and more in modern manufacture. It is made by Reid Bros. Co., Inc., Beverly, Mass.

By turning a hand wheel the speed can be adjusted from 12 to 35 f.p.m. Available in four models; mechanical units built around one-piece column casting; adjustable dust guard for work of different thicknesses; all hand wheels correctly positioned at the operator's finger tips; one shot lubrication; variable speed table control; table has three t-slots, chain driven and runs on one v-way.

Specifications of American-built surface grinders

Reid Brothers Company, Inc. — **Beverly, Mass.**

Type and Model	Capacity	T=Table Working Size TS=Table Speed	Grinding Wheel	Remarks
Surface Grinder No. 618	6"x18"x15¼" high	T=6"x18"; TS=Any Speed from 12 to 35 F.P.M.	7"x⅛"x1¼"	Four Models: 618 V, power feed table; 618 VL, power feed table, one-shot lubrication; 618H, hand feed; 618 HL, hand feed and one-shot lubrication

Brown & Sharpe Manufacturing Company — **Providence, R. I.**

Type and Model	Capacity	T= Table Size L=Max. Long. Table Travel TM=Max. Trans. Movement	Wheel Size	Horsepower
Surface Grinder No. 2L	18" long, 6" wide, 9⅛" high	T=6"x18"; L=20"; TM=6⅛"	7"x⅛"x1¼"	1½ h.p.
No. 5 Hydraulic	24" long, 8" wide, 11" high	T=8"x24"; Vert. Adjustment of wheel spindle slides=12"	10"x¾"x3"	1½ h.p.

The Taft-Peirce Mfg. Co. — **Providence, R. I.**

Type and Model	Height Under Wheel	Table Working Surface	Grinding Wheel Size	Horsepower
Surface Grinder No. 1	12"	5" to 12"; Long. Travel of Table=13⅛"	7"x⅛"x1¼"	¾ h.p.

J. B. Crosman & Son, Inc. — **East Walpole, Mass.**

Type and Model	Capacity L=Longitudinal T=Transverse	Table Top to Bottom of 7" wheel	Wheel Size	Horsepower
Surface Grinder Type Hand feed	L=8"; T=4"	10"	7"x⅛"x1¼"	½ h.p.

The DoAll Company — **Des Plaines, Ill.**

Type and Model	W=Workheight Capacity C=Chuck Capacity	T=Table Size TT=Table Traverse	Wheel Size	H=Horsepower W=Wheel Surface Speed
Toolroom Surface Grinder D6-1 Manual or Hydraulic	W=12⅛"; C=6"x18"	T=6⅛"x19¾"; TT=7⅛"x20"	7"x⅛"x1¼"	H=1 h.p.; W=6000 f.p.m.
D6-3	W=12⅛"; C=6"x24"	T=6⅛"x24"; TT=7⅛"x26"	do	do
D8-1	W=12⅛"; C=8"x24"	T=8⅛"x24"; TT=10"x26"	10"x⅝"x3"	H=3 h.p.; W=6000 f.p.m.
D8-3	W=12⅛"; C=8"x24"	T=8⅛"x24"; TT=10"x26"	14"x1"x3"	do
D10-1	W=12⅛"; C=10"x30"	T=10"x30"; TT=12"x32"	10"x⅝"x3"	do
D10-3	W=12⅛"; C=10"x30"	T=10"x30"; TT=12"x32"	14"x1"x3"	do

Grinding Wheel Speeds

Table of Speeds

Revolutions per minute for various diameters of grinding wheels to give peripheral speed in feet per minute as indicated.

Dia. of Wheel in Inches	Peripheral Speed in Feet per Minute							
	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500
	Revolu	tions pe	r Minut	e	Revolu	tions pe	r Minut	e
1	15,279	17,189	19,098	21,008	22,918	24,828	26,737	28,647
2	7,639	8,594	9,549	10,504	11,459	12,414	13,368	14,328
3	5,093	5,729	6,366	7,003	7,639	8,276	8,913	9,549
4	3,820	4,297	4,775	5,252	5,729	6,207	6,685	7,162
5	3,056	3,438	3,820	4,202	4,584	4,966	5,348	5,730
6	2,546	2,865	3,183	3,501	3,820	4,138	4,456	4,775
7	2,183	2,455	2,728	3,001	3,274	3,547	3,820	4,092
8	1,910	2,148	2,387	2,626	2,865	3,103	3,342	3,580
10	1,528	1,719	1,910	2,101	2,292	2,483	2,674	2,865
12	1,273	1,432	1,591	1,751	1,910	2,069	2,228	2,386
14	1,091	1,228	1,364	1,500	1,637	1,773	1,910	2,046
16	955	1,074	1,194	1,313	1,432	1,552	1,672	1,791
18	849	955	1,061	1,167	1,273	1,379	1,485	1,591
20	764	859	955	1,050	1,146	1,241	1,337	1,432
22	694	781	868	955	1,042	1,128	1,215	1,302
24	637	716	796	875	955	1,034	1,115	1,194
26	588	661	734	808	881	955	1,028	1,101
28	546	614	682	750	818	887	955	1,023
30	509	573	637	700	764	828	891	955
32	477	537	597	656	716	776	836	895
34	449	505	562	618	674	730	786	843
36	424	477	530	583	637	690	742	795
38	402	452	503	553	603	653	704	754
40	382	430	478	525	573	620	669	716
42	366	409	454	500	545	591	636	682
44	347	390	434	478	521	564	608	651
46	333	375	416	458	500	541	582	624
48	318	358	398	438	478	517	558	597
53	288	324	360	395	432	468	503	539
60	255	287	319	350	387	414	446	478
72	212	239	265	291	318	345	371	398

To find the peripheral speed of a wheel in feet per minute (s.f.p.m.), multiply the circumference in feet by the wheel revolutions per minute.

$$\text{S.F.P.M. of wheel} = \frac{\text{Diameter in inches} \times 3.14 \times \text{r.p.m.}}{}$$

Continued on next page

Table of Speeds—Continued

Note: "Centrifugal Force," which is the force that tends to rupture a given wheel when overspeeding, increases as the square of the velocity of that wheel. For example: the centrifugal force in a wheel running at 5500 s.f.p.m. is 49% greater than in the same wheel running 4500 s.f.p.m., although the speed is actually only 25% greater.

Peripheral Speed in Feet per Minute								Dia. of Wheel in Inches
8,000	8,500	9,000	9,500	10,000	12,000	14,000	16,000	
Revolu	tions pe	r Minut	e	Revolu	tions pe	r Minut	e	
30,558	32,467	34,377	36,287	38,196	45,836	53,474	61,116	1
15,278	16,238	17,188	18,143	19,098	22,918	26,737	30,558	2
10,186	10,822	11,459	12,115	12,732	15,278	17,826	20,372	3
7,640	8,116	8,595	9,072	9,549	11,459	13,368	15,278	4
6,112	6,494	6,876	7,258	7,640	9,168	10,696	12,224	5
5,092	5,411	5,729	6,048	6,366	7,639	8,913	10,186	6
4,366	4,538	4,911	5,183	5,456	6,548	7,640	8,732	7
3,820	4,058	4,297	4,535	4,775	5,729	6,685	7,640	8
3,056	3,247	3,438	3,629	3,820	4,584	5,348	6,112	10
2,546	2,705	2,864	3,023	3,183	3,820	4,456	5,092	12
2,182	2,319	2,455	2,592	2,728	3,274	3,820	4,366	14
1,910	2,029	2,149	2,268	2,387	2,865	3,342	3,820	16
1,698	1,803	1,910	2,016	2,122	2,546	2,970	3,396	18
1,528	1,623	1,719	1,814	1,910	2,292	2,674	3,056	20
1,388	1,476	1,562	1,649	1,736	2,084	2,430	2,776	22
1,274	1,353	1,433	1,512	1,591	1,910	2,228	2,546	24
1,176	1,248	1,322	1,395	1,468	1,762	2,056	2,352	26
1,092	1,159	1,228	1,296	1,364	1,637	1,910	2,182	28
1,018	1,082	1,146	1,210	1,274	1,528	1,782	2,036	30
954	1,014	1,074	1,134	1,194	1,432	1,672	1,910	32
898	955	1,011	1,067	1,124	1,348	1,572	1,796	34
848	902	954	1,007	1,061	1,273	1,484	1,698	36
804	854	904	955	1,006	1,206	1,408	1,608	38
764	812	860	908	956	1,146	1,338	1,528	40
732	775	818	863	908	1,090	1,272	1,464	42
694	737	780	824	868	1,042	1,216	1,388	44
666	708	750	791	832	1,000	1,164	1,332	46
636	676	716	756	796	956	1,116	1,272	48
576	612	648	683	720	864	1,006	1,152	53
510	542	574	606	638	774	892	1,020	60
424	451	477	504	530	637	742	849	72

To find the number of revolutions per minute of the wheel spindle given the peripheral speed (s.f.p.m.) and the diameter of the wheel, multiply the peripheral speed in feet per minute by 12, divide the product by 3.14 times the diameter of the wheel in inches.

$$\text{R.P.M. of wheel spindle} = \frac{\text{s.f.p.m.} \times 12}{3.14 \times \text{diameter in inches}}$$